

Representational Pseudoneglect in Line Bisection

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Words: 3631

The work presented in this paper was part of a larger project run funded in part by Grant CZB/4/346 awarded to S.D.S. and R.H.L. by the Scottish Chief Scientist Office (CSO) for which Stephen Darling was a research fellow.

Abstract

Representational pseudoneglect refers to a bias towards the left side of space that occurs when visual information is remembered. Recently there have been a number of demonstrations of such representational pseudoneglect. In the current paper we report an experiment where we adopted the classic line bisection paradigm to study representational pseudoneglect. Participants bisected horizontal lines that were shown in extra-personal space. When lines were visible on the screen, there was no evidence of any leftward bias. However, when lines were bisected from memory, participants demonstrated a clear bias to the left. This is the first demonstration of a leftward bias in bisection of remembered visually presented lines.

Representational Pseudoneglect in Line Bisection

When participants attempt to identify the middle point of horizontal lines, small average errors to the left are typically reported (for a comprehensive meta-analytic review, see Jewell & McCourt, 2000), a phenomenon has been termed ‘Pseudoneglect’ (Bowers & Heilman, 1980). A similar lateral bias has also been observed for visuo-spatial representations held in long-term memory: McGeorge, Beschin, Colnaghi, Rusconi, and Della Sala (2007) presented materials modeled on Bisiach and Luzatti’s (1978) study of representational bias in neglect patients to non-neurologically impaired participants, and observed that volunteers remembered more items from the left hand side of remembered space. They used the term ‘Representational Pseudoneglect’ to describe this specific asymmetry of visuo-spatial representation in memory. Cocchini, Watling, Della Sala and Jansari (2007) used a virtual reality task to assess representation of space behind observers (‘back space’), and found that back space to the right was perceived as smaller than back space to the left. Recently it has become clear that lateral distortions of visuo-spatial representation also occur in short-term memory for novel material. Della Sala, Darling and Logie (2010) showed that participants remembered bindings between colour, location and identity of objects from the left of visual displays more readily than those on the right. Dickinson and Intraub (2009) demonstrated that more visual items are recalled from the left than the right of unfamiliar naturalistic visual scenes. Brooks, Della Sala and Logie (2011) reported a leftwards memory bias in bisecting a wooden rod when the stimuli were presented only via touch, with no visual input. Related to these findings of bias in visuospatial representation are reports of leftward biases in representations of mental number lines: when participants are presented with a two numbers spanning an interval and asked to identify the midpoint (without explicitly calculating it), their responses typically err in a leftwards

direction (Göbel, Calabria, Farnè & Rossetti, 2006; Longo & Lourenco, 2007a; Loftus, Nicholls, Mattingley, Chapman & Bradshaw, 2009; Longo & Lourenco, 2010).

One clear issue in interpreting any lateral bias phenomena in short-term memory as *representational* in nature is to clarify whether they are indeed signs of a distortion within memory, rather than the consequence of a distortion of perception which is then exaggerated by decay in memory. Disentangling these possibilities is difficult, given that many tasks evoke perceptual pseudoneglect, including line bisection in both visual (e.g. Dellatolas, Vanluchene, & Coutin, 1996) and tactile (e.g. Bowers & Heilman, 1980; Brooks *et al.*, 2011) modalities and forced-choice comparison tasks (e.g. Nicholls, Bradshaw, & Mattingley, 1999). The present study was therefore designed to investigate biases in bisection of remembered lines, and further, to probe whether perceptual pseudoneglect and pseudoneglect of representations in visuospatial memory are both manifestations of a simple perceptual attentional bias.

In the current paper we report a line bisection study using a Method-of Adjustment task where horizontal lines were presented in distant extrapersonal space. Alongside perceptual trials, where participants bisected visible lines, we also included memory trials, where the lines were shown and then cleared from the display, and participants subsequently had to indicate the middle of where the line had been. Lines were presented in far space because viewing distance is known to modify line bisection in a fairly systematic way. Typical leftward bias on forced-choice midpoint judgment tasks is decreased (McCourt & Garlinghouse, 2000) or eliminated (Bjoertomt, Cowey & Walsh, 2002) when lines are presented in more distant space. Leftward number line bisection bias is also reduced as presentation distance increases (Longo & Lourenco, 2010). More emphatically, bisection tasks presented in far space typically demonstrate a small *rightward* bias (Varnava, McCarthy

& Beaumont, 2002; Longo & Lourenco, 2006; Longo & Lourenco, 2007b; Gamberini, Seraglia & Priftis, 2008; Lourenco & Longo, 2009). Together these studies suggest that the typical perceptual left-bias in bisection tasks is eliminated and reversed when bisection is carried out in extrapersonal space. Hence, we aimed to assess leftward bias when bisecting lines from memory using stimuli that typically do not result in leftward bias when presented without the requirement to use memory.

Method

Participants

Nineteen individuals participated in this study. All were students of the University of Edinburgh who were recruited via an employment service website. Mean age of participants was 23.26 years ($SD = 2.60$ years). Nine were male and 10 were female. Two participants identified themselves as left-handed by forced-choice self-report.

Apparatus

The experiment took place in a large windowless room with no natural daylight. Participants were seated in a chair facing a large white-painted wall. The chair was positioned so that when seated comfortably, the distance between the participant's eyes and the wall was 2.2m. Immediately behind the seat was a large stand upon which was mounted a data projector which was capable of projecting an image at a screen resolution of 1024 x 768 pixels. This display in total subtended 177 x 130 cm, equivalent to 44 x 33 degrees of visual angle. The projector was angled such that the horizontal midline of the screen was approximately eye level for participants. Participants sat with a computer keyboard on their lap, enabling them to respond to trials. The experimental materials were programmed onto a

standard Windows desktop PC using the Microsoft Visual Basic 2005 programming language.

Materials, design and procedure

Each participant took part in 120 line bisection trials, 60 in the perception condition and 60 in the memory condition. The conditions were blocked, and order of conditions was counterbalanced across participants. Three practice trials preceded each block. Participants were allowed a brief rest between the blocks. On starting each block there was a delay of 1000ms prior to the initial trial. There was also a 1000ms inter trial interval between every trial.

In each trial a horizontal line was presented along the horizontal midline of the display, with its middle aligned to the vertical midline of the display. Three line lengths were used: long, medium and short (representing 24, 12 and 3 degrees visual angle respectively). Lines were projected in white on a black background. A rectangular white border, 2 pixels in width, was present at the edge of the projected display.

On each trial, the horizontal line was initially visible for 1000ms. On memory trials it then disappeared from the screen. On perceptual trials it remained visible throughout the remainder of the trial. After a further 500ms, a marker was presented on the screen, either to the left of the left hand end of the line or to the right of the right hand end of the line (the distance between the end of the line and the marker was varied randomly between 69 and 129 minutes of visual angle and was fully counterbalanced). This marker was a vertical yellow line, 2 screen pixels in width and 21 pixels high (subtending 5 x 54 minutes of visual angle). Participants were able to move this marker left and right using respectively the 'z' key with their left hand or the period key with their right hand. Consequently, the retention interval was 500ms plus the response time.

Participants were instructed to move the marker left and right until they had decided that it was located either in the middle of the visible line (perceptual condition) or in the middle of where the line had previously appeared (memory condition). Then they pressed the space key which triggered recording of the marker position and removal of all stimuli from the display followed by the inter-trial interval.

Results

All deviations in subjective midpoint are expressed by minutes of arc (') of visual angle subtended by the difference between the subjective midpoint indicated by the participant and the objective middle of the line. Positive values represent deviations to the right, and negative values represent deviations to the left. Figure 1 shows the subjective midpoints at each individual line length: lateral biases appeared to be modified as a function of both line length and memory condition. This pattern was investigated by a 2 (memory/perception condition) x 3 (line length) ANOVA which identified a main effect of memory condition ($F(1,18) = 5.05, p = .04, \eta_p^2 = .22$) with subjective midpoints in the memory condition being significantly to the left of those in the perception condition. There was also a main effect of line length ($F(2,36) = 7.92, p = .001, \eta_p^2 = .31$). Subjective midpoints of medium and long lines were significantly to the left of subjective midpoints of short lines ($p = .005$ and $p = .004$ respectively). There was no significant difference between long and medium lines ($p = .062$). However, these effects need to be interpreted in the light of the significant interaction between length and memory condition ($F(2,36) = 6.33, p = .004, \eta_p^2 = .26$). This interaction was probed by analyses of the simple main effects of line length. Subjective midpoints in the perception condition showed no significant differences across the three line lengths ($F(2,36) = 0.76, p = .431, \eta_p^2 = .04$), whilst in the memory condition there were significant differences ($F(2,36) = 9.14, p = .002, \eta_p^2 = .34$): subjective midpoint of long

lines was left of that for medium lines, and midpoint of medium lines was left of that for short lines (long vs. medium: $p = .042$, long vs. short: $p = .003$; medium vs. short: $p = .006$).

The overall mean subjective midpoint in the memory condition was significantly to the left of the objective midpoint ($M = -6.59'$, $SD = 11.35'$, $t(18) = -2.53$, $p = .02$, $d = 0.58$), but this pattern was not seen in the perception condition ($M = -.32'$, $SD = 5.03'$, $t(18) = -.28$, $p = .78$, $d = 0.06$). Midpoint deviations did not correlate significantly across the two conditions ($r = .05$, $n = 19$, $p = .83$). Two-tailed p -values for individual one-sample comparisons against the true midpoints are shown in Figure 1. There was significant left bias in bisection in long remembered lines, whilst leftward deviation in medium remembered lines approached significance. There was significant rightward bias for short lines in the perception condition; subjective and true midpoints in all other line/condition combinations did not differ.

Discussion

When participants had to bisect a remembered horizontal line originally shown in extrapersonal space, there was clear evidence of a leftward lateral bias, with participants marking the midpoints significantly to the left of veridical midpoints. This bias seemed to apply selectively to long and medium length lines but not to short lines. This pattern is consistent with an emerging literature that representations are subject to lateral bias (Brooks, *et al.*, 2011; Della Sala, *et al.*, 2010; Göbel *et al.*, 2006; McGeorge *et al.*, 2007; Longo & Lourenco, 2007a, 2010). This study is the first to report a leftward bias in bisecting horizontal lines from memory.

In contrast, there was no evidence of systematic lateral bias in perceptual bisection collapsing across all line lengths, though there was some evidence of a *rightward* bias in the shortest lines: a pattern that is consistent with previous evidence that pseudoneglect is absent,

or even reversed, for viewing distances beyond peripersonal space (Bjoertomt *et al.*, 2002; Gamberini *et al.*, 2008; Longo & Lourenco, 2006; McCourt & Garlinghouse, 2000; Varnava *et al.*, 2002). This pattern is also consistent with the ‘cross-over’ effects seen on some types of pseudoneglect task, where participants demonstrate opposing biases on short stimuli compared to long stimuli (McCourt & Jewell, 1999; Rueckert, Deravanesian, Baboorian, Lacalamita & Repplinger, 2002). The lack of left bias on the shortest lines in the memory condition hints at a similar process, but note that a statistically reliable crossover effect was not seen for remembered lines.

Overall, this finding of a marked left bias in bisection of remembered horizontal lines in a paradigm where there is no evidence of leftward perceptual bias, and for which previous studies have shown no perceptual bias, appears to support the idea that visuo-spatial working memory itself is subject to a lateralised bias.

This pattern suggests a qualitative difference between patterns of lateral bias for memory and perception trials, itself suggesting that the mechanisms of representational and perceptual pseudoneglect on line bisection may differ. An alternative possibility is that the pattern of bias in the memory condition is related to the much smaller biases observed in perception: in other words, that the difference between memory and perception is not one of quality but of degree, and that pseudoneglect of representations merely reflects a perceptual bias that is subsequently amplified in memory. However, we note four points that seem to argue against this: firstly and most importantly, the significant interaction between memory condition and line length in the current study demonstrates that a qualitatively different pattern was observed on memory than perceptual trials: line length affected bisection on memory but not perceptual trials. Secondly, there are several comparable bisection studies which have noted *rightward* perceptual bias in distant space (Longo & Lourenco, 2006, 2007b; Gamberini, *et al.*, 2008; Lourenco & Longo, 2009), and the proposition that we are

misinterpreting a leftward bias with a small effect size as a null effect is not easily accommodated to this literature. Thirdly, Longo and Lourenco (2010) recently showed evidence of leftward biases in representational number line tasks in a sample who showed rightward bias in a perceptual bisection task, in both cases in extrapersonal space, demonstrating at the very least that neglect of represented information does not precisely mirror perceptual neglect. Finally, evidence of representational pseudoneglect on complex representational tasks based on LTM (Cocchini *et al.*, 2007; McGeorge *et al.*, 2007) is inconsistent with the amplification account. Consequently, the most parsimonious explanation for the current data is that perceptual and representational pseudoneglect are separate phenomena.

In any visual line bisection task, a visual perimeter is always present, for example the edge of a piece of paper or a computer monitor. In order to replicate this feature of visual arrays in our projected setup, we included a border around our stimulus array. In addition, stimulus lines were not jittered around the true screen midpoint. However, participants cannot have been merely bisecting the interval formed by the border or learning how to locate the middle of that interval because the border was invariant in size: if participants bisected the interval and this bisection was biased this lead to a stable bias rather than the observed relationship between midpoint deviation and line length.

It can be argued on the basis of this study that the reasonably clear distinction between peri- and extra- personal space observed in perceptual pseudoneglect is less clear-cut in visuo-spatial representations. So far all available evidence from mental imagery, mental number lines and the current study suggests that visuo-spatial representations are biased to the left (although leftward error for number line bisection decreases as a function of distance, the left bias is not eliminated even at distances that result in right bias on perceptual trials: Longo & Lourenco, 2010). One possible explanation of this pattern might be that

representations of items are all treated as if they were within peripersonal action space, even if they are outside of such space in the physical environment, an idea that is consistent with the idea that all represented items can be acted upon mentally (e.g. Logie, Engelkamp, Dehn & Rudkin, 2001; McGeorge *et al.*, 2007). Data from line bisection tasks in which tools (such as physical pointers) are used seems to be compatible with this proposal: in such studies there is evidence of leftward bias in bisection in distant space, both in real (Longo & Lourenco, 2006) and virtual reality (Gamberini *et al.*, 2008) environments. It is possible that the tool enables the extension of ‘peripersonal’ space to include any area within its direct action range. Nonetheless, in the current study, the precise relationship of extrapersonal physical space (where the response cursor was presented), and the representation of the remembered line, in peripersonal representational space, remains unclear. It is possible that active maintenance of such bindings in working memory is necessary, and it may alternatively be this, rather than the retention of peripersonal information *per se*, that is subject to a lateral bias. Future research will need to refine understanding of the processes underlying leftward distortions of mental space.

An interesting alternative explanation of representational neglect data could be related to the nature of visual attention deployed. McCourt and Jewell (1999) demonstrated that distortions in representation of horizontal lines occurred at an object-centered level, rather than at an egocentric level, as left bias was not strongly affected by the position of lines relative to the observer within the visual array. It is possible, however, that once the line disappeared in the memory condition of the current study, participants reverted to an egocentric attentional allocation which may have been subject to stronger leftward bias. Recently, De Schotten, *et al.* (2011) have shown that similar representational biases appear to be associated to lateral asymmetries in brain networks.

In the light of all the above, it is clear that developing models of memory must account for lateral representational biases, including those on bisection tasks. Logie (1995; 2011) has argued for a visual cache within visuo-spatial working memory that retains recently presented novel material, such as horizontal lines, but that is separate from visual perception, imagery and from activated representations in long-term memory (e.g. Borst, Niven and Logie, 2011; Logie, Beschin, Della Sala & Denis, 2005; van der Meulen, Logie & Della Sala, 2009). It is possible that this cache is subject to a lateral bias to the left.

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Figure 1. Subjective midpoint deviations (in minutes of arc) across three line lengths.

Error bars indicate SE of the mean. Statistical significance in one-sample comparisons against veridical midpoints are shown.

